The Development of Numerical Competence

Animal and Human Models

Edited by

Sarah T. Boysen
E. John Capaldi

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CHAPTER FOUR

Counting by Chimpanzees and Ordinality Judgments by Macaques in Video-Formatted Tasks

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INTRODUCTORY CONSIDERATIONS

Whether animals can learn symbols, use them representationally and abstractly, and use them to solve problems remain questions of high interest. Research since the mid-1960s, but particularly during the 1980s, indicates that chimpanzees are capable of mastering and using symbols in ways that parallel human use of words (Savage-Rumbaugh, 1986, 1987; Savage-Rumbaugh, McDonald, Sevcik, Hopkins, & Rubert, 1986; Savage-Rumbaugh, Sevcik, Brakke, Rumbaugh, & Greenfield, 1990). In accordance with the comparative perspective, the bases for human cognitive competence appear to be shared in significant part with our nearest living relatives, the great apes, Pongidae (Rumbaugh, 1990b). Those findings are, in turn, part of a growing number of comparative psychological studies that document impressive cognitive operations of animals and birds in general (e.g., Roitblat, Bever, & Terrace, 1984).

Counting Versus Sensitivity to Quantities

Animals' abilities to respond to different quantities and human abilities for complex mathematics are assumed in this chapter to be part of a continuum of processes provided by evolution of the brain and experience. Research into animals' sensitivities to specific and relative quantities of

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things and events, presented simultaneously or serially across time, and their abilities to "keep track" of quantities as they accumulate are probably near the lower end of that continuum. Their ability to count, if extant, would be toward, though remain substantially distanced from, the other end of that continuum that provides for mastery of advanced mathematics.

This perspective leaves unanswered, of course, the question as to just what the primitive criteria are for symbolic counting. How will we know that it is operational in animals? At most, its manifestations will be modest, perhaps even reminiscent of trace elements otherwise overshadowed in a complex compound. Notwithstanding, discernment of these manifestations in animals surely will lead to new perspectives regarding brain structure and cognitive function, as well as other perspectives addressing questions of human evolution.

Tactics

Research tactics into the quantity-based skills of primates at the Language Research Center have focused on *productive* counting skills through use of video-formatted tasks. As is discussed in this chapter, these tactics call for the subjects to produce a specified quantity of events as defined by the value of a given trial's *target number*. To date, the things "to be produced" through the subject's use of a joystick-controlled cursor have emphasized (a) the touching of boxes with the consequence that they change in appearance or, in some instances, disappear from the screen, and (b) the placement of cardinal numerals or black dots on each of a number of boxes of varying sizes and presented in random arrays so as to "count out" the quantity called for by the value of the target number for each trial.

The target number's value is subject to change on a random basis across trials and the computerized presentation and automatic recording of the subjects' performances can rule out inadvertent cuing. The procedures require that the subject (a) discern the value of the target number at the beginning of each trial, (b) monitor what has been done since the beginning of each trial, and (c) determine when the "counting" is complete and the trial should be terminated.

The procedures do not allow for correct performance to be based on recognition or labeling of familiar and predictable quantities that recur across trials. Specifically, they do not permit the subject to *label* a familiar visual array of items as "containing *n* items" with a numeral. Rather, they ask the subject to *produce* "a count" on a piece-by-piece or response-by-response basis in response to various target numbers. To the degree

that chimpanzees can do so, it is held that true counting skills are being tapped.

Although animals' skills are very circumscribed by comparison to those of humans, this does not detract from their scientific value. On the contrary, that they are extant in *any* measure is of substantial value. As stated earlier, to the degree that such skills in animals can be discerned, we have promise of defining important dimensions of brain-behavior relationships and, also, basic parameters of entry-level numeric competence.

Learning Sets and Caveats

For all who work with the larger-brained monkeys and great apes and for those who are interested in reading of the animals' competencies, a caveat regarding their advanced one-trial, learning-set (Harlow, 1949) skills merits emphasis. It is a well-established fact that great apes and some monkeys (notably the rhesus macaque, *Macaca mulatta*) are capable of learning new discriminations within a single trial *and* also are capable of reversing a learned discrimination within one trial (e.g., Rumbaugh & Pate, 1984). Consequently, the successive readministration of what were novel test trials at the beginning of any test of competence can permit the chimpanzee to relearn and/or modify prior learning so rapidly and efficiently that it can give specious readings of competence, for example with numerals and other symbols. Such performance can be a reflection of discrimination learning-sets rather than ability to use numeric cues with competence. Especially when reward is given for each correct or desired kind of response on so-called test trials, the successive readministration of what were initially novel test trials or tests of generalization affords the perfect opportunity to learn anew via learning sets available to a sophisticated primate.

By definition, novel test trials can be given only once. After their first administration they are, in some measure, familiar and their readministration affords additional training. The use of novel test trials to determine the natural processes underlying primates' performances is highly recommended. Data from those trials should be reported apart from subsequent readministration of the once-novel trials because of the special value they have—and deserve—in the assay of skills. It is performance on the first administration of novel test trials, not on the readministration of them over and over, that provide the purest assay of subjects' competence for the conceptual use of numbers versus their competence for rote associations/pairings between sets/arrangements of items and numbers and vice versa.

Presentations of Testing Materials—Risks

There should be ready agreement to the procedure that *blind* tests should mean the subject cannot be cued by the experimenter's activities in preparing materials for specific trials or by the experimenter's activities while the subject is executing a choice. The risks of cuing are greatly increased when the subject has a small and finite number of things/cards handled and presented personally by the experimenter in an unchanging pattern or order across a span of trials.

Controls and objective methods of inquiry and data capturing have been and must remain the hallmarks of experimental psychology. They should become and remain the hallmarks of all research into the numeric and symbol competencies of both humans and nonhumans. The rhetoric of the research report should never supplant relevant data and the implementation of adequate controls.

Need for Sufficient Amounts of Data

Researchers also should strive to obtain data in amounts sufficient to make tests of significance, in the final analysis, an exercise of the obvious. This effort can tax the creativity of the researcher who, in working with but a few numerals, might soon learn that there is limited option for the construction of novel test trials with which to assay competence after training. Modern technology and particularly the use of computer-based systems can be helpful in solving that and other problems. It is highly adaptable to many of the other needs of research with nonhuman primates (e.g., Rumbaugh, Richardson, Washburn, Savage-Rumbaugh, & Hopkins, 1989; Washburn, Hopkins, & Rumbaugh, 1989).

PERCEPTIONS OF QUANTITIES

Not surprisingly, chimpanzees—hearty eaters that they are—prefer larger rather than smaller portions of foods and drinks (e.g., Menzel, 1960). Survival across eons has perfected the processes whereby primates differentiate relative mass and/or amounts of items almost instantaneously.

How do organisms that have not developed a formal counting system judge relative quantities? What are their limits? How do they do this when the items comprising clusters of quantities are not contiguous? Can they "combine" items of different clusters or groupings so as to judge two or more clusters as containing more than those of others? And if they can do so, are the processes for so doing requisites for addition with

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numerals? As summarized here, we have investigated these questions, in part, by testing the chimpanzee's ability to choose between pairs of quantities of preferred foods—bits of chocolates.

Summation Studies with Chimpanzees

Two language-trained chimpanzees, Sherman and Austin (*Pan troglodytes;* see Savage-Rumbaugh, 1986, for a review of their language training), gradually came to choose the larger quantity of chocolates when given a choice between two trays, each with a *pair* of food wells containing chocolate chips (Rumbaugh, Savage-Rumbaugh, & Hegel, 1987; see Fig. 4.1). It is important to note they were not required to do so in order to get chocolates. On the contrary, they were always allowed to eat what they chose. Notwithstanding, their choice of the tray with the greater sum remained high (>90%) even when tested with novel arrays and was a function of the ratio formed by the combined number of chocolates of the two trays. The coarser the ratio (e.g., 2:3 vs. 7:8), the more likely it was that the pair with the larger amount would be selected. The findings were interpreted to suggest that the chimpanzees could (a) subitize (e.g., determine specific, small quantities without counting) quantities of the individual wells that formed the right and left pairs, and then (b) sum the paired subitized values, so as (c) to choose the pair that offered the greater total quantity. Summation was defined as the reliable choice of "one of a *pair* of quantities whose overall sum is greater than the sum of another pair of quantities for all possible pairs within a stated numerical range" (Rumbaugh et al., 1987, p. 107).

A detailed assessment was made to determine the degree to which correct performance might be the result of avoiding the pair that had the least number of chocolates in a single well or by selecting the pair that had the greatest amount in a single well, rather than summing across wells (Rumbaugh, Savage-Rumbaugh, & Pate, 1988). These alternative hypotheses were tested by (a) devising pairs such as 4,3 versus 5,3, in which the choice for the greater total could not be made by avoiding the side with smallest single quantity in one of its wells (i.e., each pair had a well with 3 chips) and (b) devising pairs such as 3,5 and 4,5 in which the choice for the greater total could not be made by choosing the pair that had a well with largest quantity (i.e., each pair had a well with 5 chips).

The ratios formed by the summed values per tray ranged from 1:2 to 7:8. Once again, noncorrection testing procedures were employed, meaning that even "error" choices of the smaller sum were rewarded. The chimpanzees *always* got to eat the contents of both wells of whichever pair they selected.

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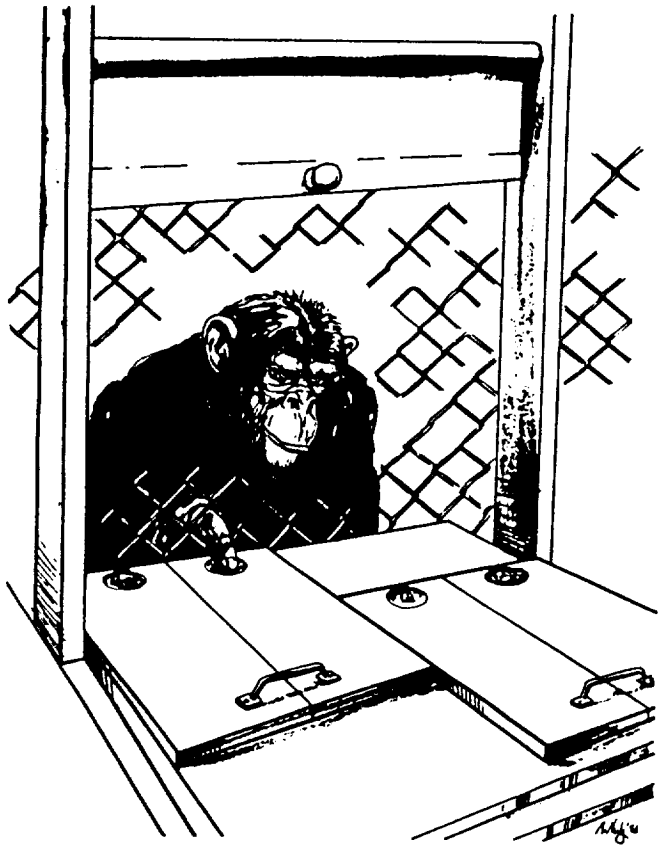

FIG. 4.1. The apparatus used in summation studies.

Choices of the greater sum across conditions ranged from 87%–100% and the distribution of errors for the three conditions were quite similar. No single strategy, other than focusing on the entire array and comparatively summing both sides, could seemingly support choice of the greater sum in the conditions of this study. With these trials randomly interspersed with trials of still other types, it is unlikely that an array of strategies apart from summation could be successfully employed. No signal was given, for example, to inform the subject that on a given trial it was a "select-the-tray-with-the-greatest-single-amount trial" or an "avoid-the-tray-with-the-smallest-single-amount trial," and so on. If the chimpanzees had attempted to use such a group of strategies, they would

first have had to evaluate the entire array in some manner to select the strategy appropriate for that trial. This seems quite unlikely, particularly because they always were permitted to eat the chocolates regardless of whether their choice was for the greater quantity. The most parsimonious interpretation inferred that Sherman and Austin used a single strategy across all trials, one based on the summation of quantities per pair as a basis of choice.

More recently, Pérusse and Rumbaugh (1990) replicated the basic phenomena associated with summation and found that summation is manifest even when ratios defined by the two pairs of quantities forms a ratio as fine as 8:9. Through use of varied colors of food bits, it was demonstrated that the choices are not a function of overall brightness associated (or confounded) with the number of chips in each pair of wells. Additionally, the subject does better if it has only two wells, rather than two pairs of wells, between which to choose. This implies that when the chimpanzee chooses between pairs of wells they must negotiate the distance between each pair by some process whereby the quantities of the two wells are pooled, combined, or summed, and this is more difficult than when they have only to negotiate the discontinuity of constituent food bits when they are judging the larger of two clusters.

Skills for summation are viewed as possible precursors to the emergence of formal arithmetic operations, such as addition and subtraction. But, children's entry-level arithmetic operations likely require the ability to count. To pursue research into some possible requisites to formal arithmetic operations, research was designed to explore whether a chimpanzee might be able to count.

CAN A CHIMPANZEE LEARN TO COUNT?

Could a chimpanzee learn to enumerate items and thereby to *produce* specific quantities of responses and attendant consequences in accordance with the values of different Arabic numerals? This question would call for tactics that contrast with those used in studies of *counting* or *number usage* that asked whether an animal could learn one or more associations between Arabic numerals and various arrays constructed and presented by the experimenter. That kind of skill might be reducible to learned associations between numerals and specific arrays that, if correct, nets reward. It would not necessarily entail enumeration and the learning of the values for each of several numerals.

A relevant and important study of earlier years is, of course, the one reported by Ferster (1964), who taught two chimpanzees to match binary digital arrangements with corresponding quantities of items rang-

ing in numbers from 1 to 7. After receiving approximately 500,000 trials, the subjects could reliably label various quantities by producing appropriate binary expressions, regardless of the shape, size, or arrangement of items on the display. Notwithstanding that this was an impressive accomplishment for the chimpanzees, Ferster did not claim that his subjects were counting because there was no indication that they enumerated specific items.

Somewhat similar is a study reported by Matsuzawa (1985) with his language-trained chimpanzee, Ai. Ai used each of 6 keys, glossed as numbers, to label the numeric quantity of arrays comprised of from 1 to 6 items. However, Matsuzawa did not claim that Ai had literally counted the number of items per display. Ai's learning might have been limited to associative couplings between various Arabic numerals and the perceptual patterns defined by various quantities of the items displayed (i.e., toothbrushes, etc.). This consideration does not rule out, however, that Ai might have learned more than that. Indeed, this seems possible when we consider Matsuzawa's report that when the display consisted of objects of two colors, Ai responded with the correct numeral contingent on the color of object "to be counted" as designated, across trials, by the experimenter. (For other recent studies of chimpanzee counting, see Boysen, chap. 2 in this vol.)

Another favorite and important study of note was by Davis and Memmott (1983). Rats inhibited bar pressing for food until three shocks had been received during a 30-minute time period. After the third shock, the rats' bar pressing for food increased markedly, which suggested that the rats were counting the number of shocks—an interpretation that Davis recently moderated. Davis (1984) reported that a raccoon could be taught to select a box containing three items of any sort from an array of cubes containing 1, 2, 3, 4, or 5 items. Davis and Bradford (1986) subsequently found that rats could be taught to travel to a third box regardless of its spatial location. Much earlier, Hicks (1956) reported similar results in the development of a concept of "threeness" in the rhesus *(Macaca mulatta).* These studies demonstrate animals' abilities to differentiate a single, specific quantity apart from others. Again, however, the distinction between learning to perceive a specific quantity versus counting its constituent items should be kept clear.

Learning to respond to a specific quantity, even accumulated shocks across time, had at one time been thought to reflect a form of counting. According to a simpler and more likely explanation, a recurring experience associated with a context will become established as a "perceptual norm" (Rumbaugh et al., 1987) for that specific context. According to this perspective, whenever a familiar number-based context is encountered, the subject will behave in compliance with the *norm* for that con-

first have had to evaluate the entire array in some manner to select the strategy appropriate for that trial. This seems quite unlikely, particularly because they always were permitted to eat the chocolates regardless of whether their choice was for the greater quantity. The most parsimonious interpretation inferred that Sherman and Austin used a single strategy across all trials, one based on the summation of quantities per pair as a basis of choice.

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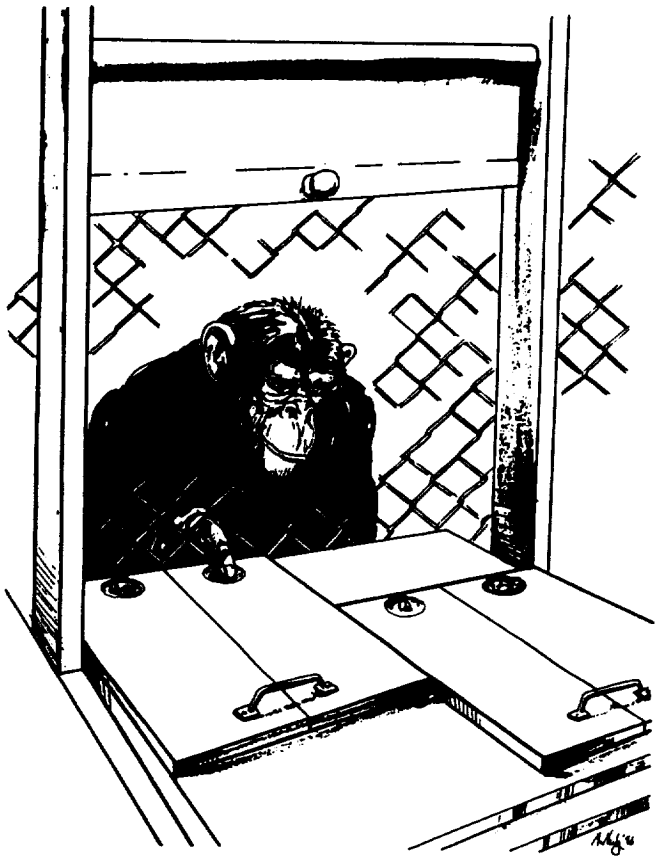
text. The subject, for example, might wait and brace for the final shock of a fixed and predictable quantity (so as to resume eating) or continue to move about (as looking in boxes of varied quantities of things or past boxes in a row) until that norm is *reinstated* or *perceptually matched* (e.g., the requisite shadows/patterns of entrances to tunnels have been perceived). Only then is behavior substantively redirected (e.g., eating is resumed, a choice of boxes is made, an entrance is selected, etc.). But the behavior that transpires as the subject awaits congruence with a context-specific normative experience does not have to entail the counting of events. It might just entail the ability to discern whether a current perception does or does not match the familiar norm based on past experience. (The construct of perceptual norm predates a related one that entails Rosch's view of *prototype* argued by Thomas & Lorden, chap. 6 in this vol.)

By contrast to studies of the type reviewed earlier, the operations of formal counting are quite different. Formal counting is comprised of constituents of interacting cognitive processes. There is no simple criterion for it (criteria for counting discussed later are either from or were suggested by Gelman & Gallistel, 1978). To conclude that an animal counts, one must, among other things, demonstrate (a) *how* it enumerates items of sets, things, or events; (b) that it partitions the counted from the uncounted; (c) that it stops counting appropriately; and (d) that it can count different quantities and kinds of things.

Enumeration has become, quite justifiably, the focal point in studies of counting (Davis & Perusse, 1988), but enumeration must not just be suggested by appearances (i.e., "touching" the items to be counted), which might be ritualistic and without function. Rather, the actual functional role or value of any act of enumeration should be validated. Simply because a child can say "one, two, three" while pointing to objects does not mean the child can count. It must be established that the child can count out just one or two as well as three items and with different kinds and quantities of items and events in various contexts. To be able to enumerate thus implies that competencies for cardinality and ordinality are present.

Cardinality refers to the tags or labels used during counting. If used in the appropriate order, those labels enable counting with precision. By a one-to-one assignment of a tag/label to each item in a set (the one-one principle), one may determine the total count or number of items. But that the subject "knows" that the last item's tag also defines the total items in that set (the cardinal principle) is not necessarily apparent. It must be empirically validated.

Essentially anything might be counted (the abstraction principle). Neither the nature nor quality of items or events determine the basic operations of counting.



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Choices of the greater sum across conditions ranged from 87%–100% and the distribution of errors for the three conditions were quite similar. No single strategy, other than focusing on the entire array and comparatively summing both sides, could seemingly support choice of the greater sum in the conditions of this study. With these trials randomly interspersed with trials of still other types, it is unlikely that an array of strategies apart from summation could be successfully employed. No signal was given, for example, to inform the subject that on a given trial it was a "select-the-tray-with-the-greatest-single-amount trial" or an "avoid-the-tray-with-the-smallest-single-amount trial," and so on. If the chimpanzees had attempted to use such a group of strategies, they would

Each tag/label used to count has its position or sequence relative to all others. Once counted an item can be said to have been the "third" or the "fifth" counted, and so on. But the *total count* of a set is not influenced by the order or sequence through which the members of that set are counted (the order-irrelevance principle). To count, an organism must know each number's ordinal rank and that each number's cardinal value serves to declare the total quantity counted at each step in the counting process (e.g., the item assigned "three" is the third one and, also, that three items have been enumerated).

Whether a chimpanzee could learn to count, as evidenced by producing the appropriate number of responses to the Arabic numerals 1, 2, and 3, was recently addressed, keeping several of the previous conceptual and procedural caveats at the fore (Rumbaugh, Hopkins, & Washburn, 1989; Rumbaugh, 1990b; Rumbaugh, Hopkins, Washburn, & Savage-Rumbaugh, 1989; Rumbaugh, Savage-Rumbaugh, Hopkins, Washburn, & Runfeldt, 1989). The goal was to have the chimpanzee (Lana, at the time a 17-year-old adult female with an extensive language training history; Rumbaugh, 1977) produce a number of responses in accordance with the values of specific Arabic numerals—1, 2, and 3. She would have to respond so as to produce 1, 2, or 3 discrete units/events—not simply label arrays. In the final test, Lana would have no residual visual feedback or cumulative tally to determine whether she had already produced an array of 1, 2, or 3. Rather, she would have to remember what she had done within the course of each trial in order to complete it successfully. Most training and all test trials would be unique in that (a) the value of the number to which she was to count (i.e., the *target* number), (b) the placement of that number on the monitor, and (c) both the quantity and placement of items available with which she could proceed with the count were randomly determined each trial.

All phases of the present study were run on a Commodore 64 computer with a Sony XY-2400 color monitor. Lana had readily learned how to manipulate a joystick to move a cursor relative to targets on the monitor by observing a researcher. All procedures used to teach Lana the counting behaviors employed her precise control of the joystick and were broken down into three major categories: (a) number orientation and number matching, (b) removal of perceptual or spatial relations, and (c) generalization to new shapes and colors.

The typical trial that Lana saw on the monitor early in her training is shown in Fig. 4.2. Lana's first job was to take the cursor to the target number (which was always 1, 2, or 3). As soon as she did so, the items (selection boxes) with which to proceed with the count then appeared in the bottom half of the screen. Lana's second job was to take the cursor and to attempt to count out 1, 2, or 3 of those items, depending on the value of the target number on a given trial. On the kind of trial por-

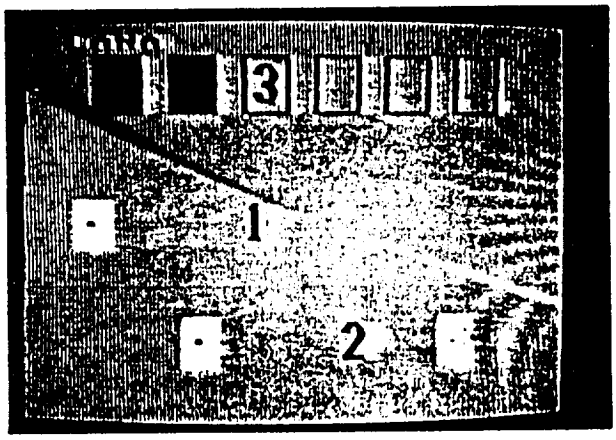


FIG. 4.2. A trial typical of Lana's early training. The target number is 3 on this trial. Consequently, it appeared in the third box in the row of feedback boxes at the top of the screen. (If the target number had been 2, it would have appeared in the second box from the left, and so on.) As portrayed here, Lana has already removed two of the selection boxes from the lower portion of the screen. When the first one was removed, the number 1 appeared in its stead and the left-most feedback box turned blue; when the second one was removed, the number 2 appeared in its stead and the second feedback box turned blue. The figure shows that Lana now has the cursor on the box in the lower right-hand corner of the screen. A 3 will appear in its stead, and the box containing the target number will turn blue. For the trial to be completed satisfactorily, Lana will next have to return the cursor to that target number.

trayed in Fig. 4.2, as each box was counted a feedback score-keeping box turned blue (beginning with the left-most feedback box in the top row) and a tone sounded briefly. When she set about to terminate a trial, she had to return the cursor to the target number. If she returned to the target number too early or too late, it was treated as an error, in which case she received no reward and the computer sounded a raucous tone.

The number of items in the bottom-half of the screen varied randomly from trial to trial and generally exceeded the value of the target number, so there was no reliable or normative pattern toward which she could work to produce and then use as a basis for terminating the trial. Across the course of 20 software programs, Lana's training always entailed some alteration in the aforementioned display in order to rule out, in final test, the use of all cues and strategies other than counting as the basis for correct performance.

In the final step of the study, Lana's ability to respond to each number without the benefit of residual/cumulative visual feedback (i.e., feedback boxes appearing and/or changing shapes and colors across trials, as in

some programs) was tested. Only the tone sounded as each box disappeared when touched by the cursor (Fig. 4.3). Thus, Lana had only her memory of performance within the trial at hand to discern when she should stop the count so as to end the trial successfully.

Figure 4.4. depicts the results from the first 73 no-feedback test trials across which the target numbers were randomly determined. Lana clearly responded significantly above chance for all numbers. Interestingly, she was somewhat better, though not significantly so, on those trials that had no visual feedback than on those that did. It merits emphasis that each test trial was unique in that the position and value of the target number as well as the number and array of selection boxes (from which Lana

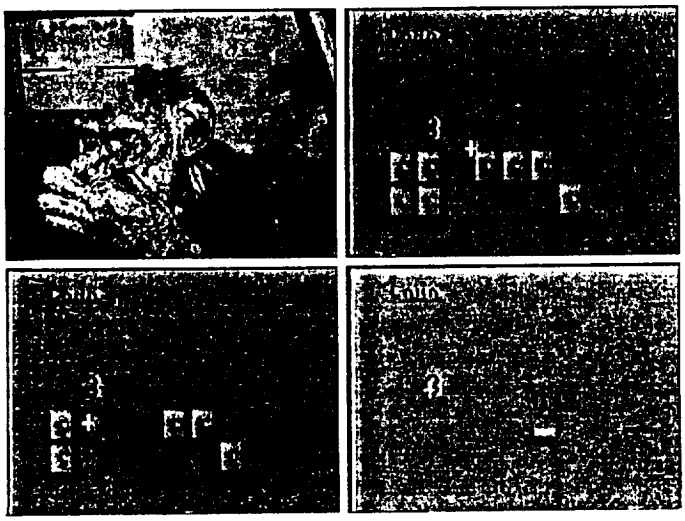
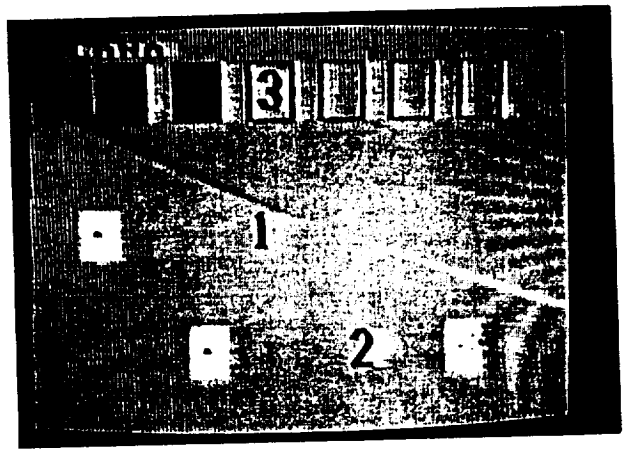


FIG. 4.3. An example of the screen's appearance during a trial on final test of Lana's counting where she had only her memory of intratrial performance to guide her successful performance (e.g., no feedback boxes, as in Fig. 4.2, or other cumulative score-keeping system was present to assist her). The target number might have been 1, 2, or 3. Here, the number is 3 (top right), and Lana must remove any three boxes from those shown in the lower portion of the screen—the quantity and array of which was randomly determined each trial. On this particular trial, she first removed the third box from the left, top row; then the second box from the left, top row; and then the second box from the left bottom row. The array as modified by Lana's performance is portrayed in the lower left of the figure. (A tone sounded briefly when each box disappeared.) She then returned the cursor to the target number for successful completion of that trial (lower right of this figure shows her cursor back on "3" and all but a small portion of one box removed from the screen as the trial ends).



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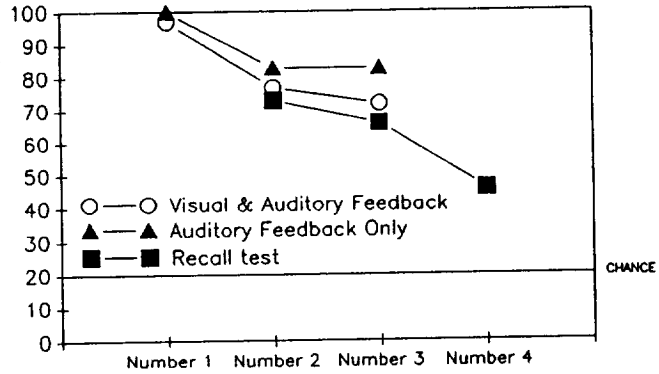

FIG. 4.4. Percentage correct for Lana on visual and nonvisual feedback final test trials for numbers 1, 2, and 3. (See text for further details.) The recall test and the first tests with number 4, randomized with numbers 1, 2, and 3, were given 3 years after the initial study had been conducted.

counted) were randomly determined. Consequently, she could not just remove boxes in order to leave in place a configuration of selection boxes of a given number or of a given array. Since the data of Fig. 4.4 were published, Lana has demonstrated ability to remove 4 boxes in test where the numeral "4" was randomly presented across trials with 1, 2, and 3.

The results of this study are in support of the hypothesis that Lana was counting. Her final test afforded no residual record for her to accumulate as a "score" as she removed, via counting, selection boxes from the lower portion of the monitor. Consequently, she had only her memory of *intratrial* events—what had been done and what had yet to be done on each of series of uniquely configured test trials—as the basis for termination of a given trial. For that to be possible, her skills of enumeration and memory must have entailed elements of both ordination and cardination.

Just how she tagged each box as it was removed to achieve a count equivalent to the value of a given trial's target number is not known. It might have been visual imagery that generated a 1, 2, and 3, in turn, or it might have been something idiosyncratic and quite foreign to representation by Arabic numerals. Notwithstanding, those numerals had been available to serve various functions throughout her training, so it is possible that they served as tags for her entry-level counting skill.

It merits emphasis that Lana was not highly stylized/ritualistic or rhythmic in her removal of selection boxes to achieve the count. From time to time, she would pause midtrial, then resume her work. A review of

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the 1,442 taped trials from all parts of her 20 training programs revealed that she paused on 303, or 21%, of them. If when she resumed her work she made no change in tactics (e.g., continued the cursor path in progress prior to the pause) she completed 210, or 71%, of the trials correctly—only 10% less than her overall accuracy of 81% on those 1,442 trials. More interesting is the finding that on the 93 trials where Lana changed her tactic after the pause (e.g., changed the direction of the cursor's path, as from a selection box to the target number to finish the trial, or from the target number so as to remove yet one more selection box before completing the trial), she was 61% correct! Consequently, we conclude that whenever Lana altered her tactics *midtrial* (i.e., after pausing), it served on a better-than-chance basis to enhance the probability that she would complete a given trial correctly. This finding suggests that Lana's intratrial memory was one of attentively monitoring events that served as a basis for deciding "what to do next"—to remove another selection box or to return the cursor to the target number.

Some of the occasions for Lana's pausing was due to the activities of other chimpanzees, including the demands and antics of her own offspring, that distracted her within the course of trials. Notwithstanding, she did remarkably well. A related question is: Just how much distraction might Lana tolerate within the course of trial and still be correct? The answer to this would tell us something about the short- and long-term memory operations that supported correct counting.

Her skill with the joystick entailed a very reasonable approximation of a productive enumerative act (i.e., touching the cursor to boxes) that (a) partitioned, in any order, the counted from the uncounted, and (b) served to produce the set/quantity to-be-counted, as declared by the target number's value on each trial. To attempt to reduce Lana's counting to prototypic matching is to deny the construction of her behavior. The "prototype," if one were to insist on positing one, was in Lana's learning of the specific quantity that equaled 1, 2, 3, and 4 boxes *to be removed.* And, that is counting!

We have no evidence to suggest that chimpanzees have a strong "sense of numbers." Although they can discern small differences between quantities, they have not yet given us reason to believe they have any comprehension of the principle that one can always count to a next higher value. The history of ape language research is replete with proclamations that apes cannot do this or that, which subsequently they have been shown able to do, thus we do not say that apes cannot count higher than this or that value.

Although Lana came to count through the course of a series of training programs, not all of them were likely necessary. Quite possibly some

phases may have even been too redundant or conservative, and in effect impeded her progress. Notwithstanding, they constituted our first exploration into chimpanzee counting skills with a video-formatted task. They allowed us to move from an initial program that by intent was rich with redundant information to cultivate her counting competence in final test. Gradually, all redundant, all nonnumeric cues, and all residual and obvious accumulative methods whereby Lana might have been "keeping score within trials" were deleted. What remained was a competence to respond to each of three Arabic numbers in a differential and relatively accurate manner—in a manner that we term *entry-level counting.*

It is readily acknowledged that the counting skills of humans clearly entail many more operations than those acquired or demonstrated by Lana. Research with her counting skills are limited in that they have yet to be tested in other contexts. Whether they can provide for the labeling of various sets appropriately has not been tested.

Research in progress with Lana and other language-experienced chimpanzees (Sherman and Austin) supports the view that they can count at least up to 4 or 5 boxes by placing either Arabic numerals or black dots on boxes in accordance with the value of a given trial's target number (Fig. 4.5; Rumbaugh, 1990a, June).

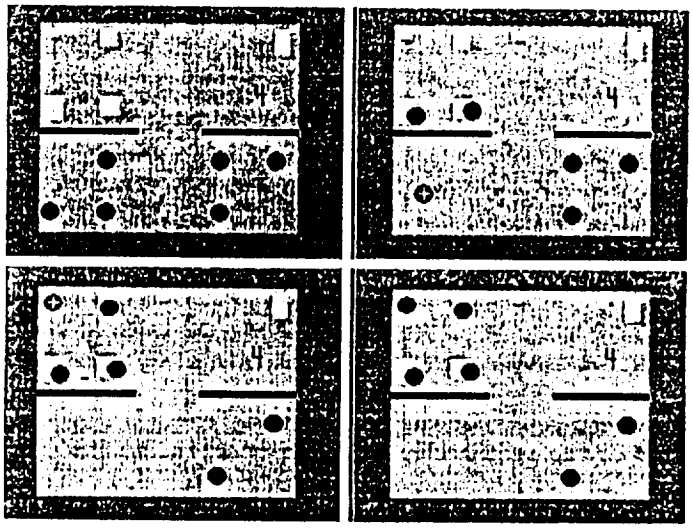

FIG. 4.5. In this trial of the dot task with a target numeral of 4, Lana must place a dot on each of four boxes (upper left and right, then lower left of figure) before terminating the trial by returning the cursor to the target numeral (lower right).

RHESUS MONKEY COMPETENCIES FOR ORDINALITY

Washburn and Rumbaugh (1991) reported that through the use of video-formatted training that rhesus *(Macaca mulatta)* learned the relative values of Arabic numerals 0 to 9. The ability of rhesus to use the joystick with great skill in video-formatted tasks, on the Language Research Center's Computerized Test System (LRC-CTS), provided a ready means whereby they could be presented with all paired combinations of numerals within selected ranges and be permitted to choose one on each trial. As a consequence of selection of a numeral, a corresponding number of pellets was automatically dispensed for the subject to eat. For example, if on a given trial the rhesus had a choice between the numerals 3 and 5 and selected the 3, it received 3 pellets—the delivery of each one being accompanied by a brief tone. If, on the other hand, it selected the numeral 5, it received 5 pellets.

Initial training was limited to the numerals 0 through 5, with a 0 being one of the paired numerals every other trial. If 0 was selected on a given trial, no pellets were delivered to the subject. Within only 900 trials the animals were well above chance.

Subsequent training included numerals 6 through 9. Both rhesus monkey subjects reliably came to prefer the larger numeral of each pair—even 9 over 8. On final test with the administration of novel pairs withheld from prior training (6,5; 7,6; 9,8; 6,4; 7,5; 9,7; and 8,5), one monkey was without error on their first presentation, hence significantly better than chance.

The temporal intervals between the delivery of successive pellets were then systematically varied and were concluded not to have been a determinant of choice of numerals. (Intervals were such that the delivery of 2 or 3 pellets might span a longer time than the delivery of a greater amount, such as 8 or 9.)

Thus, even rhesus monkeys have the well-honed ability to differentiate quantities of things that occur even serially across time. They also can learn quite readily to associate arbitrary symbols (i.e., Arabic numerals) with different quantities and select symbols preferentially on the basis of their relative food-values. Their mastery of the numerals' ordinal ranks was so complete that it readily transferred to an array of numerals simultaneously presented (e.g., when the monkeys had five randomly selected numerals presented simultaneously in random arrays across trials, they "counted down" by selecting with high reliability the highest numeral remaining on the screen—though they were not required to do so to get rewarded). In response to these arrays both animals significantly chose the numerals in a descending sequence—9, 8, 7, 6, and so on.

phases may have even been too redundant or conservative, and in effect impeded her progress. Notwithstanding, they constituted our first exploration into chimpanzee counting skills with a video-formatted task. They allowed us to move from an initial program that by intent was rich with redundant information to cultivate her counting competence in final test. Gradually, all redundant, all nonnumeric cues, and all residual and obvious accumulative methods whereby Lana might have been "keeping score within trials" were deleted. What remained was a competence to respond to each of three Arabic numbers in a differential and relatively accurate manner—in a manner that we term *entry-level counting.*

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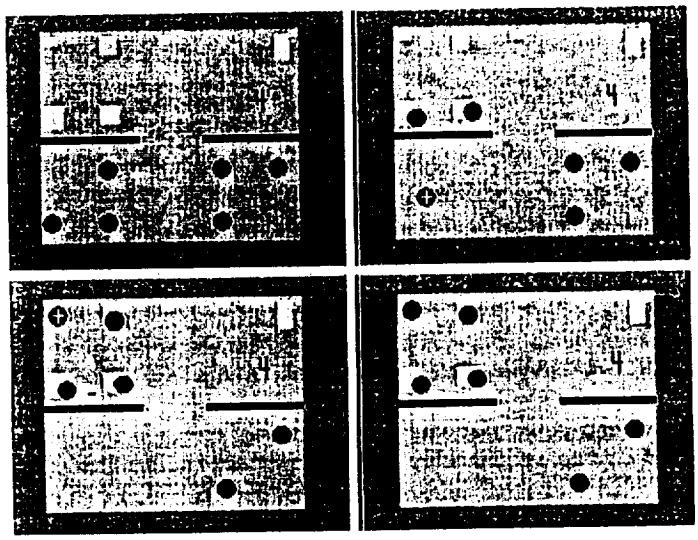

FIG. 4.5. In this trial of the dot task with a target numeral of 4, Lana must place a dot on each of four boxes (upper left and right, then lower left of figure) before terminating the trial by returning the cursor to the target numeral (lower right).

Were the rhesus counting? We do not argue that they did because there was no evidence the monkeys were enumerating pellets. Neither have we discerned that they had learned the cardinal values of the numerals and that each numeral of the sequence differed only by a value of 1 pellet. (Lana had learned that a target numeral of 2 required "one more" than 1 and the a target numeral of 3 required "one more" than 2.) Notwithstanding, the monkeys chose the numerals in reliable accord with their ordinal ranks, which is a necessary, though not sufficient, condition for it to be concluded that counting was operative.

Exactly how the monkeys were able to respond even to novel combinations of arabic symbols in accordance with the numerals' ordinal values remains a question for ongoing research. Performance on novel pairs eliminates the possibility that the monkeys had simply amassed 45 discrete-pair associations—selecting the 7 in a 7:6 pair, for example, because "7 is the correct answer." However, the judgments may have arisen from a matrix of knowledge about relative values, for example "7 is greater than 6, and 7 is greater still than 5" and so forth. It is this matrix of relative values—the knowledge that any two numerals differ by a specific degree (number or amount) and the ability to respond reliably to numerals based on both the difference and the degree of difference—that is the main support of the claim for ordinal judgments by the monkeys.

Alternatively, of course, the monkeys may have perceived the numerals as representing absolute quantities or hedonic values (see Thomas, this volume; e.g., a larger quantity of pellets is more pleasurable/gratifying than is a smaller quantity) rather than as members of an ordinal series, just as they might prefer to select red over yellow over green, and so forth. Indeed, we have reported similar preferences for task selection (Washburn, Hopkins, and Rumbaugh, 1991) that do not imply an ordinal sequence of tasks. However, when these preferences map perfectly and reliably on the critical dimension that distinguishes the members (e.g., wavelength for color, difficulty for task, or number of pellets as in our paper), one is strongly inclined to cite this dimension as the basis for judgment.

Granting then that the monkeys based their responses on number (or amount, as we noted), we do not wish to discount at all the possibility that the judgments may have reflected knowledge of absolute number, or that indeed this may even appear to be the more parsimonious interpretation. However, judgments of theoretical parsimony can be tricky, particularly when Morgan's canon meets Occam's razor: Although knowledge of absolute number introduces fewer conceptual steps or operations, the operations themselves are more complex than those required for mastery of a matrix of relative-order associations. Indeed, the cognitive competencies of the monkeys would seem to be most flattered if responses are in-

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Although Lana came to count through the course of a series of training programs, not all of them were likely necessary. Quite possibly some

terpreted as based on conceptual comparison of absolute quantities ("9 > 8") rather than on acquired knowledge about order ("9 comes after 8").

We have based our claim for ordinal judgments on the monkeys' ability to assert, for example, that 9 > 8 > 7 > 6 > 5. In point of fact, the monkeys generally judged, for example, that 9 > 8, 7, 6, and 5; that 8 > 7, 6, and 5; that 7 > 6 and 5; and that 6 > 5. We see neither the logic nor the parsimony of distinguishing between these two assertions, nor between them and "9 comes after 8 which comes after 7 . . .", although other investigators may wish to maintain the distinctions. Thus, we risk that our judgment of relative parsimony may differ from that of other investigators—confident that in either case the findings are noteworthy. It is clear that the monkeys made precise relative numerousness judgments across a range of ordinal symbols differentiated by a single pellet, and that, regardless of whether the monkeys made judgments based on knowledge of absolute number or relative order, responding was not limited to any simple learning of the "correct" choice for each possible array of numerals.

A PERSPECTIVE

Studies summarized in this chapter serve to emphasize nonhuman primates' abilities to learn symbols' values and to use them to adaptive advantages. Their skills in this regard have been underestimated, in measure because of past technological limitations placed on researchers. With the advent of computer technology, new and efficient research tactics, that provide for excellent controls and replication of studies between laboratories, promise to yield important and more accurate assays of nonhuman primates' abilities for symbols and numbers and more accurate definitions of what it means to count.

ACKNOWLEDGMENTS

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PART TWO

COUNTING: CRITERIA AND RELATIONS TO BASIC PROCESSES

terpreted as based on conceptual comparison of absolute quantities ("9 > 8") rather than on acquired knowledge about order ("9 comes after 8").

We have based our claim for ordinal judgments on the monkeys' ability to assert, for example, that 9 > 8 > 7 > 6 > 5. In point of fact, the monkeys generally judged, for example, that 9 > 8, 7, 6, and 5; that 8 > 7, 6, and 5; that 7 > 6 and 5; and that 6 > 5. We see neither the logic nor the parsimony of distinguishing between these two assertions, nor between them and "9 comes after 8 which comes after 7 . . .", although other investigators may wish to maintain the distinctions. Thus, we risk that our judgment of relative parsimony may differ from that of other investigators—confident that in either case the findings are noteworthy. It is clear that the monkeys made precise relative numerousness judgments across a range of ordinal symbols differentiated by a single pellet, and that, regardless of whether the monkeys made judgments based on knowledge of absolute number or relative order, responding was not limited to any simple learning of the "correct" choice for each possible array of numerals.

A PERSPECTIVE

Studies summarized in this chapter serve to emphasize nonhuman primates' abilities to learn symbols' values and to use them to adaptive advantages. Their skills in this regard have been underestimated, in measure because of past technological limitations placed on researchers. With the advent of computer technology, new and efficient research tactics, that provide for excellent controls and replication of studies between laboratories, promise to yield important and more accurate assays of nonhuman primates' abilities for symbols and numbers and more accurate definitions of what it means to count.

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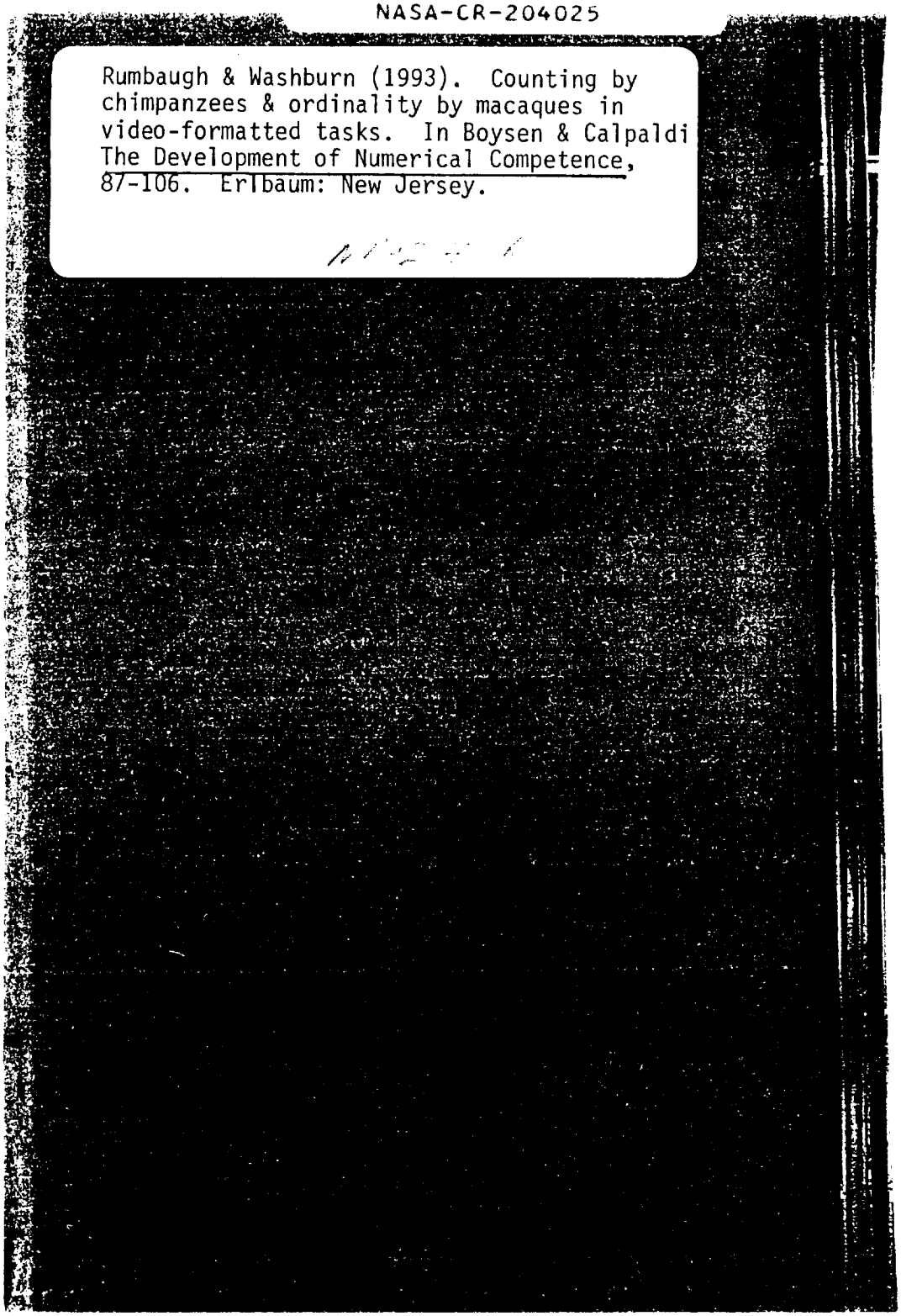

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